SPATIAL COHERENCE OF NONLINEAR, NONSTATIONARY, NON-GAUSSIAN OCEAN WAVES ON A ONE-MILE SCALE FROM SCANNING ALTIMETER RADAR

Leon E. Borgman
L.E. Borgman, Inc.
2526 Park Avenue Laramie, WY 82070
Phone: (307) 742–3178 Fax: (307) 742–2583 Email: borgman@cyberhighway.net
http://gallatin.gg.uwyo.edu/~borgman

Ronald W. Marrs
Department of Geology and Geophysics
University of Wyoming
Laramie, WY 82071
Phone: (307) 766–2320 Fax: (307) 766–6679 Email: rwmarrs@uwyo.edu
http://www.uwyo.edu/A&S/geol/faculty/marrs.htm

Contract No. N00014–98–C–0206

LONG-TERM GOAL

The lack of good ocean surface data on the one-mile or more scale is a major stumbling block for proper evaluation of proposed Mobile Offshore Base (MOB) conceptual designs (Fig. 1). A general model and associated software for stationary, linear, statistical, directional wave systems has been available for some time. If that model can appropriately be used for design of marine mega-structures, then there is no problem in proceeding with conceptual MOB designs and their evaluations. However, it is believed that storm waves might be locally stationary, but on a larger area scale might be nonstationary with patches of clusters of high waves, giving local variances inconsistent with stationary, linear, statistical, directional wave systems. There is a strong need for more knowledge concerning nonlinearity and coherence of storm waves on the mega-structure scale.

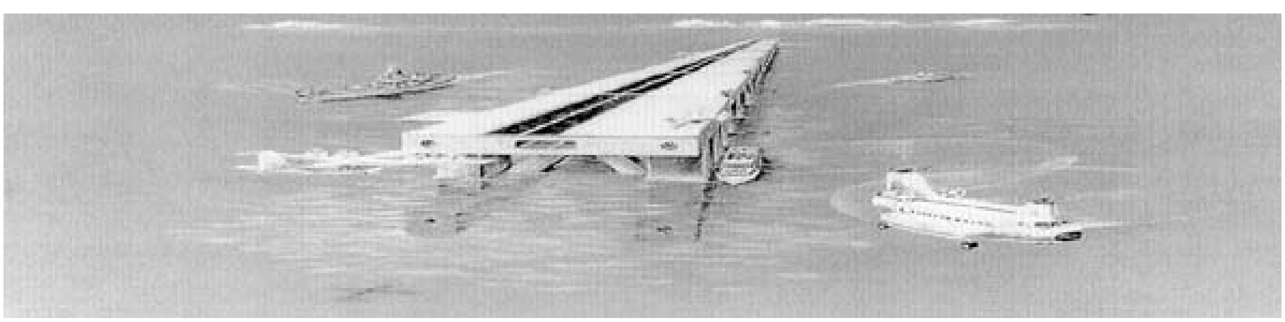

Figure 1: An artist's conception of the Mobile Offshore Base (MOB).

OBJECTIVES

Sea surface elevation data previously collected by Walsh *et al.* (1989, 1996) with an airborne scanning altimeter radar (SAR), together wtih new measurements of hurricane storm waves being collected during the 1998 hurricane season are scheduled for analysis. Objectives are to (1) gain familiarity with a small selection of typical data, (2) to develop software and procedures for displaying the data for visual overview and editing, and (3) to start an examination of spatial clustering of large waves, as representative of the many questions on nonstationarity which are to be examined in subsequent phases of the project.

APPROACH

It was desirable to commence the study of nonlinear wave features in a simple one-dimensional frame of reference. Concepts and results could then be extended to the more complex situation of two horizontal space dimensions. Consequently, three flights at low altitude with narrow swath were selected for review and for use in the study of wave groups. One flight at a much greater altitude was included as a first effort at examining short-crested waves in a substantially wider flight swath. No attempt was made to choose particularly good or bad data, so the cases used may be thought of as typical examples of what may be encountered in processing the remaining data.

Standard image processing representations of the data were examined first, since already existing software was readily available for their preparation.

Block Diagrams: In order to keep x and y coordinates on an equal scaling, the block diagrams had to be long and narrow, and required examination from a distance in order to display the whole flight. If a section of the block is examined from closer up, the data imperfections of spikes and jiggles become obvious. Clearly some smoothing is necessary if the wave features are to be made more apparent.

Gray-Scale Imaging: One way to "smooth" the visual representation is to go to a gray-scale photographic representation. Although these images give a good representation of a few waves as they might appear to the eye, they weren't very satisfactory for evaluating statistical imperfections and structure. The block diagrams seemed a little more useful, but this rendition was achieved at the expense of considerable vertical distortion.

Sequence Plots: The next things tried were representations from time series. The nadir line of pixels (at pixel 32 in the transverse scan) were graphed as a sequence of values in the flight direction directly below the airplane. The graph of this data carries considerable statistical information. Clearly noise is present as evidenced in the sharp "jitter". Consequently it seemed reasonable to filter the sequence with a low-pass filter, cutting off the signal at about spatial frequency 0.012 cycles per meter. Considerable care was made in designing the filter so that it left the spectral density completely unchanged at frequencies lower than 0.01 cycles per meter, because these lower frequency components are most likely to affect large structures.

Shift Plots: The 64 sequences were plotted with an incremented shift on the y axis for each graph. That is, the elevations, $y(x)$, for the jth line of pixels parallel to the flight line, were graphed as

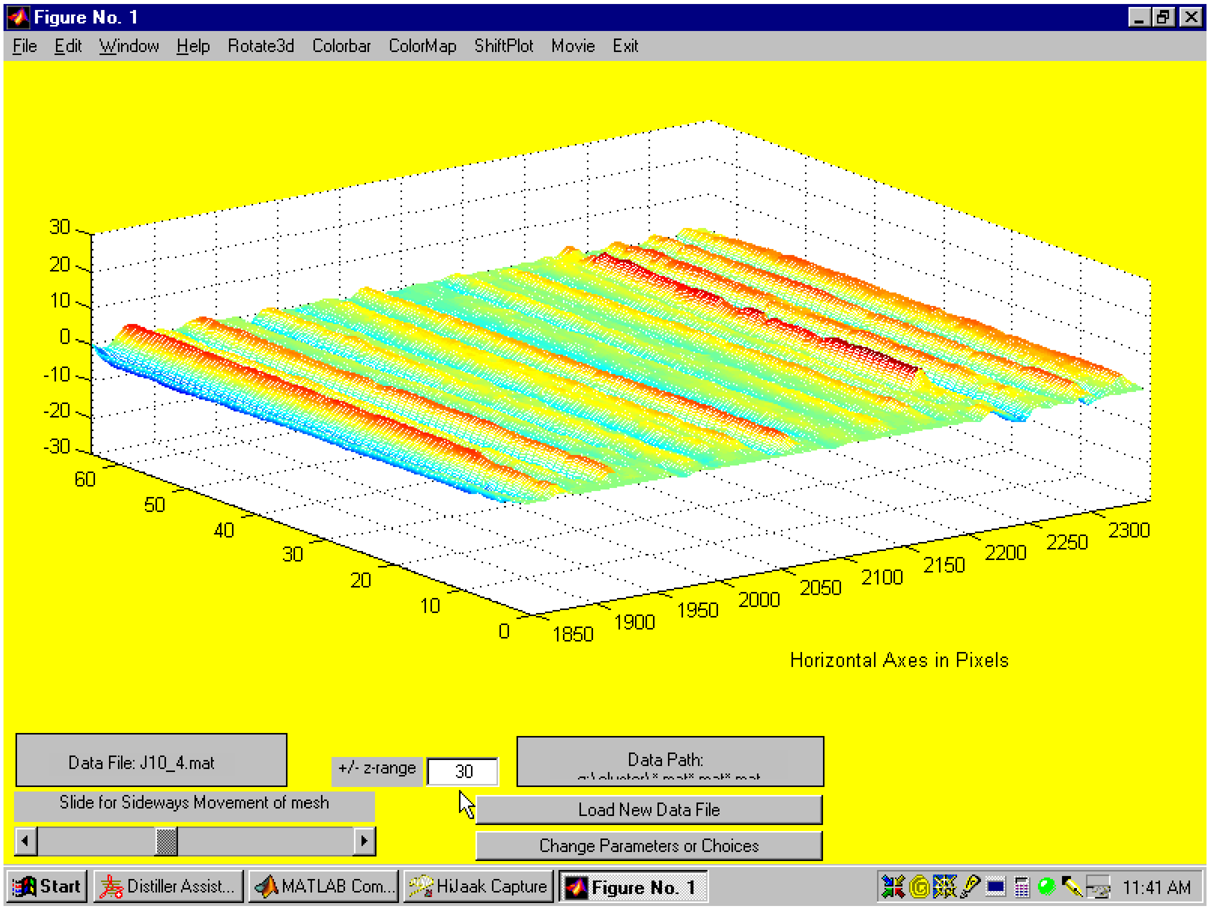

Figure 2: A mesh plot of a section of SAR data.

$y(x) + j * \Delta$ versus x. By making Δ smooth, each line was very near its neighbor and small relative changes and relations were obvious to the eye. All the 64 flight lines are shown in reasonable detail, interrelations "jump out" to the eye, and all the information is compressed into five pages.

Mesh Plots: The MATLAB software used in most of the analysis has standard routines for contours and mesh plots. Both were tried, and the mesh plot seemed to relay the most visual information. An example of the mesh plot is provided in Fig. 2.

A Graphical User Interface (GUI) for Data Processing: The analysis and graphs used in the investigations were custom-coded with the MATLAB software langauge. This required many small specially-written subroutines and considerable editing of each function to adapt it to the desired figures and computations. Once the best general preprocessing routines were established, it seemed desirable to develop a more easily used system. Accordingly, a GUI based on MATLAB (version 5) tools was developed for scrolling shift plots and mesh plots along the flight line.

WORK COMPLETED

Three tasks were completed this year subsequent to the project starting date May 14, 1998. A pilot study of four data flights was used to search for the best graphical mode of representation for editing the data and seeking out statistical relations. A type of plot which we call a "shift plot" proved most useful. Secondly, a statistical study of frequencies of groups of large waves was made with the pilot study data sets to see if wave nonlinearity might manifest itself by producing grouping that was inconsistent with what would be present in linear wave trains with the same spectra. This inconsistency was found to be true for the pilot study data, although the amount of data analyzed is insufficient for a very strong conclusion. Thirdly, a graphical user interface (GUI) was developed with MATLAB code to facilitate easy processing of the rest of the flight data with the most informative graphical representations applied in the pilot study.

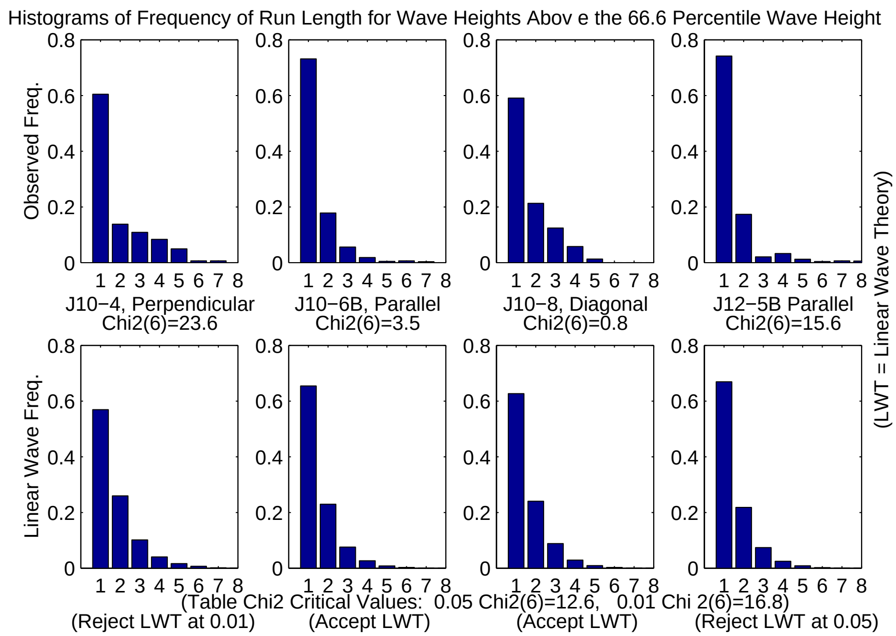

Figure 3: Histogram comparisons of wave grouping in data with grouping in linear wave simulations.

RESULTS

A careful examination of the data analyzed thus far yields a somewhat startling result. The two parallel-to-crest flights have a higher frequency of runs of length 1.0 (no grouping at all in this direction) than do the linear wave simulations. One might speculate that nonlinear processes encourage large waves to link together in groups in the direction of travel. At right angles to this the energy is perhaps attracted sidewise into a single group, rather than allowing large short-crested waves to travel side by side. This conjecture is illustrated in Fig. 4 together with a block diagram of a section of flight data. It is entirely too soon in the study to take these results as being certain because more data need to analyzed; but the results are quite intriguing.

IMPACT/APPLICATION

A marine engineer designing floating mega-structures needs to develop a full appreciation of the hazards that may arise in the operational life of the structure. This project will contribute to

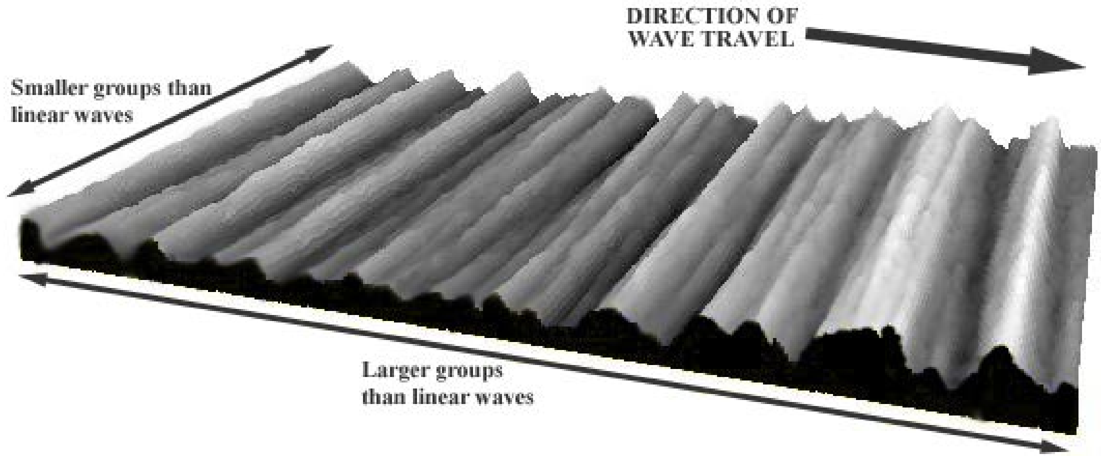

Figure 4: Block diagram of a section of waves in the SAR data, together with the statistical conclusions from the histograms in Fig. 3.

that and will attempt to develop numerical algorithms that allow real ocean data from SAR to be applied numerically to design decisions.

TRANSITIONS AND RELATED PROJECTS

Possible interactions with other related projects, and their use of the software developed in this study, were discussed in a recent meeting of ONR investigators. However, this project just got started this summer, and it is too early to be specific about which interrelations may develop.

REFERENCES

Walsh, E.J.; Hancock, D.W.; Hines, D.E.; Swift, R.N.; and Scott, J.F. (1989), An observation of the directional wave spectrum evolution from shoreline to fully developed, *J. Phys. Oceanog.*, **19**, 670–690.

Walsh, E.J.; Shay, L.K.; Graber, H.C.; Guillaume, A.; Vandemark, D.; Hines, D.E.; Swift, R.N.; and Scott, J.F. (1996), Observations of surface wave-current interactions during Swade, *The Global Atmosphere and Ocean System*, **5**, 99–124.

PUBLICATIONS

Borgman, L.E. (1998), Directional wave polyspectra beyond stationarity, *OTC 8659*, Offshore Technology Conference, Houston, Texas May 4–7.

Borgman, L.E.; Marrs, R.W.; Walsh, E.J.; Reif, S.L.; and Andrews, M.A. (1998), Clustering of ocean waves, *Journal of Shore and Beach*, (to appear).